Design, Implementation, and Operation of a Mobile Honeypot

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Abstract

Mobile nodes, in particular smartphones are one of the most relevant devices in the current Internet in terms of quantity and economic impact. There is the common believe that those devices are of special interest for attackers due to their limited resources and the serious data they store. On the other hand, the mobile regime is a very lively network environment, which misses the (limited) ground truth we have in commonly connected Internet nodes. In this paper we argue for a simple long-term measurement infrastructure that allows for (1) the analysis of unsolicited traffic to and from mobile devices and (2) fair comparison with wired Internet access. We introduce the design and implementation of a mobile honeypot, which is deployed on standard hardware for more than 1.5 years. Two independent groups developed the same concept for the system. We also present preliminary measurement results.

1 Introduction

Scanning Internet hosts to initiate a denial of service, to find an exploit, or to discover an unsecured remote access is typically the first step of an attack towards Internet devices. In former times those attacks have been reserved to traditional server systems [1]. Today, not only desktops but also mobile devices (e.g., smartphones) offer intentionally external services.

Mobile phones are particularly threaten by attacks. They are almost always connected with the Internet. Their limited resources do not allow the application of commonly used security mechanisms. In addition, many end users disable security barriers, which have been introduced by vendors, when they root or jailbreak their mobile [2]. From this perspective it is reasonably to assume that attackers specifically target on mobile devices. A plethora of research discussed network-based vulnerability of mobiles and proposed solutions (e.g., [3]), but up until now unsolicited remote accesses to mobiles have not been studied in detail. In this paper, we argue that a measurement infrastructure is required which aims to quantify and to analyse the amount of remote attacks on mobiles.

A common technique to study attack behavior is the deployment of honeypot. A honeypot is a trap for collecting data from unauthorized system access—in this analysis via IP—initiated by remote parties. However, the term "mobile honeypot" is not well-defined and there is only very limited work on the design of a measurement system that allows for both, the analysis of the mobile as well as non-mobile world. In this paper we extend our previous work [4] and make the following core contributions:

1. We introduce the detailed design and implementation concepts of a mobile honeypot. The principles of the system have been developed independently by two groups. It has been running for approximately 1.5 years and is part of the early warning system of one of the largest ISPs in Europe. The honeypot system abstracts from unnecessary mobile aspects, which allows us to deploy the same software base on standard PCs that are connected to different types of Internet access.

2. We report on preliminary measurement results. This includes a summary of our current observations of attack behaviour on smartphones, as well as a statistical analysis of unsolicited traffic [5]. The traffic measurement presents data from November 2012, which we compare with common wired Internet access and with our results from January 2012 [4]. Surprisingly, we do not find a significant amount of attacks specific to mobiles, which indicates that adversaries operate almost independently of the actually captured host.

The vulnerability of smartphones is based on multiple aspects. This paper concentrates on remote attacks

via the Internet. One might argue that a mobile operator usually do not assign public IP addresses to mobiles and that NAT techniques protect the systems against malicious access. We think the mobile environment needs an early and continuous analysis as well as appropriate tools. There are still operators providing public IP addresses. With an increased deployment of IPv6 the IP address assignment policy will change as several application scenarios requiring direct access without NAT traversal.

The remainder of this paper is structured as follows. In Section 2 we introduce background and discuss related work in the context of mobile honeypots. We present the design space, implementation, and deployment aspects of the mobile honeypot system in Section 3. Our measurement study is discussed in Section 4. We conclude with an outlook in Section 5.

2 Background and Related Work

2.1 Trapping Attackers with a Honeypot

In contrast to other security measures that ultimately try to keep the attacker out of the system, honeypots are meant to be compromised. Their value lies in luring the attacker into entering a system and collecting information on how this is done.

A honeypot is typically classified as low interaction or high interaction honeypot and client or server honeypot. A *low interaction honeypot* primarily collects information about the attacker and detects known attacks. The limited level of interaction between attacker and target is achieved by not providing fully functional services but only emulations thereof with known exploits. On the other hand, a *high interaction honeypot* provides a fully functional system. They are used to reveal current and new attacks that do not have to be catered for when setting up the honeypot. Since the high-interaction honeypot is a fully functional system, it has to be closely monitored for successful attacks to prevent the attacker from using the honeypot to target other systems on the network. *Server honeypots* provide vulnerable services to malicious clients. Their focus is in protocol and service specific vulnerabilities. A server honeypot does not offer any legitimate services, any connection by a client can be treated as an attack. *Client honeypots* take the role of a vulnerable client trying to find malicious servers.

2.2 Wireless versus Mobile Honeypots

Physical and virtual honeypots [6] have been studied in detail, however, there is only little work in the field of mobile-related honeypots. Mobile honeypots have to be distinguished from *wireless honeypots* [7], [8], which focus on the attacks on the wireless technology. The term *mobile honeypot* is used here referring to honeypots that focus on attacks on mobile devices.[1] They can either be mobile themselves in running on the mobile device in which case they would usually be low interaction honeypots used for deception and detection of known attacks. This also greatly reduces the possibility of the device itself being compromised. On the other hand they can be dedicated devices up to high interaction solutions set up to expose unknown attacks. Mobile honeypots in the sense of honeypots focussing on mobile devices are for example developed by the Chinese Chapter of the Honeynet Project [10]. They are using prototype deployments of honeypots for Bluetooth, WiFi, and MMS. TJ OConnor and Ben Sangster built honeyM [11], a framework for virtualized mobile device client honeypots, which emulates in particular wireless technologies. Mulliner *et al.* [12] propose HoneyDroid, a specific mobile honeyot that exclusively runs on smartphones. We argue that those approaches complicate the measurement across different types of systems. In addition, they are only required if the hardware characteristics are relevant for the study.

3 Mobile Honeypot System

Our primary goal is the design of a measurement system that captures traffic characteristics of malicious behaviour on mobile devices and allows for comparison with non-mobile environments. In addition to these statistical observations, we are interested in the more detailed procedure of potential attackers (e.g., which software do they infiltrate). A common technique is the application of a honeypot. In this section, we discuss appropriate levels of abstraction to cover the mobile environment without losing comparability with non-mobile setups. The mobile honeypot has been designed and implemented coincidently by two different groups. Both groups approached completely independently at the same conclusion.

Attacker Model In this paper, we concentrate on a system that analyzes malicious access via the Internet on smartphones. We argue for a typical attacker model. The attacker tries to compromise the smartphone via unsolicited remote connections [3], or captures the mobile using malware and initiates further denial of service attacks to other mobiles or non-mobile hosts [13], [14]. In any case, such remote attacks are bound to the network layer

[1] Note that the term "mobile honeypot" is also used to describe other scenarios. Balachander Krishnamurthy [9] uses it to describe prefixes of darknet address space that (1) are advertised to upstream ASes, making the information mobile, and (2) change aperiodically, moving the darknet in the address space.

and moreover do not address specifics of mobile hardware, but solely target at the system level. The adversary actively tries to find vulnerable nodes and may use additional information such as IP topology data or web server logs to differentiate mobile and non-mobile networks.

3.1 Design

The term “mobile honeypot” is not well-defined. The general design space is based on the following three questions: (Q1) Is it necessary that the probe runs on a mobile device—if yes which device type (notebook versus smartphones versus …)? (Q2) Is it necessary that the honeypot runs on a mobile operating system (PC emulation versus mobile device)? (Q3) To which network is the mobile honeypot connected (DSL network versus UMTS network versus …)?

According to the attacker model, there is no need to operate the mobile honeypot on real smartphones. This reduces complexity in building the honeypot and simplifies long-term operation.

As underlying operating system we decided for Linux. This has two advantages: (1) Most of the currently deployed smartphones use the Android OS. We conducted fingerprinting tests using the well-known tools Nmap and Xprobe, which try to guess the operating system. Both tools cannot distinguish Android from current Linux versions. (2) Using Linux enables us to re-use existing honeypot tools independently of the deployment in mobile or non-mobile scenarios. This allows us the ensure comparison between different systems.

An important change is the adjustment of the virtual file system that is presented to the attacker. It should reflect the directory structure of a typical Android system.

To increase the *attractiveness* for an adversary, we account for “rooted” (or “jailbreaked”) devices. A rooted device grants additional system access to the user. It allows post installation of additional services such as HTTP or file sharing. A honeypot system that intends to capture tools introduced by the attacker need to emulate a rooted smartphone. Note, considering rooted devices provides the attacker with *supplementary* features and thus does not exclude off-the-shelf mobiles.

Regarding the third question we argue that the mobile probe should connect to a real mobile network. Otherwise, an attacker could detect performance differences (e.g., network delay) in advance. In addition, a connection via a real mobile operator ensures the assignment of a topological correct IP address. Note, for an attacker it is easy to identify relevant IP blocks, either by testing or analysing meta data in the Internet registries.

As we are mainly interested in the analysis of statistical effects and not on dedicated attacks, the mobile honeypot is primarily based on low-interaction honeypots.

3.2 Implementation

Software To implement the proposed honeypot system, we use multiple well-known honeypot tools. The mobile honeypot consists of the following different subhonyepots: Kippo, Glastopf, and Dionaea.

Kippo is a dedicated SSH honeypot that emulates remote terminal sessions. Login access is secured by a trivial password, which allows an attacker to gain easily access to the system. The user account is granted administrator privileges. An attacker can execute common programs, as well as download and install additional tools. The honeypot records downloaded files in the background for later analysis. To protect the honeypot against compromising operations, all infiltrated actions are only valid within the current attack session and the execution of newly installed programs is prohibited. Note, this does not conflict with our objectives, as we are interested in the principle behaviour of the attacker.

Glastopf implements a web-based media server providing an upload form. Uploaded data can be stored in a simulated smartphone file system. This honeypot emulates typical vulnerabilities of a web system.

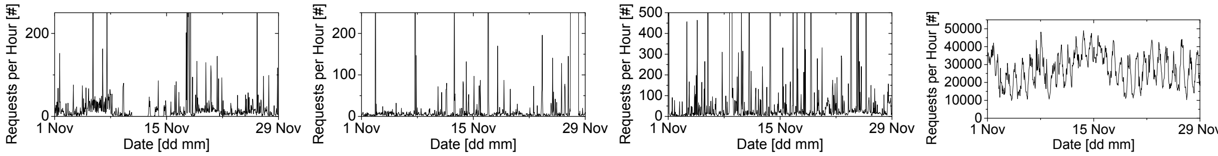
Dionaea is used to emulate TFTP and FTP services.

To detect generic attacks, we use *Honeytrap*. It listens on all other transport ports and is particularly useful to analyse statistical effects. Worms, for example, do not need a protocol compliant negotiation of transmission parameters but send data via an existing TCP connection without waiting for corresponding replies.

Network connectivity Several mobile operators provide only private IP addresses. Nevertheless, there is a continuous demand for public IP addresses. In particular with an increased deployment of IPv6, we expect a significant change, which will enable mobile nodes to participate in the Internet without NAT traversal.

In addition, many mobile operators, at least in Germany, prevent the communication between end devices per default in NAT domains. For this reason, the deployed mobile honeypot presented in this paper is connected via the Deutsche Telekom, one of the largest telecommunications companies in Europe. They allow to choose an alternative Access Point Name (APN) that provides public IP addresses and thus intra-domain communication.

Note, the proposed honeypot system can be connected to any other type of network access, such as a DSL home network or business Internet access. This allows us to use the same system in different network environments (i.e., wired and wireless infrastructures), and to monitor attack behaviour from different vantage points in the Internet without loosing reproducibility.



(a) Mobile network (b) DSL network (c) Darknet (d) University network

Figure 1: Comparing amount of attacks on different between mobile and non-mobile honeypot probes, Nov. 2012

3.3 Deployment

We started the deployment of the honeypot systems at common PC hardware mid of 2011. Since then they run continuously and surprisingly well. The mobile honeypots of both independent groups include one iOS and two Android probes. They are connected via an USB stick to the UMTS network. All data is exported in a five minute interval to the early warning system of one European's largest telecommunication companies. To prevent interference and preserve bandwidth of the UMTS link, log data is transmitted using a separate LAN connection. Data from or to the log server is excluded from further analysis.

In addition to the measurement probes that use a mobile Internet access, we deployed the same system at three nodes connected to different non-mobile networks. In detail, the network access is (1) a university network, which reflects a stable and well-known open access; (2) a DSL network, which represents a common home uplink; (3) a darknet, which highlights background noise, because it does not announce any service. These characteristic access types allow for comparison of the mobile measurements with non-mobile environments.

4 Measurement Study

In this section, we present preliminary measurement results of the mobile honeypot system. We could not find substantial disagreements between the different mobile probes. We count any external connect to the honeypot system as an attack, its source IP address is called the attacker.

4.1 General Observations

In general, the number of attacks targeting the mobile probe do not significantly differ from honeypots connected to the Internet via typical wired access. It seems that the attackers scan the Internet without considering specific network types but try to exploit as many devices as possible.

The procedure of the attacker is almost identical to the wired probes. After gaining successfully a shell login and executing some common commands, an adversary usually downloads malicious software and tries to integrate the honeypot into an IRC-botnet. The attacker initiates commands almost independently of the local system properties even if this leads to conflicts (e.g., non-existing directories). We frequently observed that the adversary navigates through the file system directories following the common Linux structure. Specific Android processes have been ignored.

To our surprise, we observed very rarely an intruder that conducted a mobile-specific attack. For example, after establishing an SSH connection to the mobile honeypot, one adversary targeted on the address book as well as the stored photos of the emulated mobile system. Those attacks are usually performed manually and not based on scripts. However, the mobile honeypot did not captured Android- or iOS-specific malware or Exploits.

4.2 Comparative Detail Analysis

For our subsequent analysis we focus on network traffic and compare effects on the mobile honeypot with non-mobile systems. We consider the measurement period of November 2012.

Most of the external requests are related to the university network (cf., Table 1). The DSL and UMTS honeypots measure on average 21 and 55 attacks per hour, respectively. More surprisingly, the darknet experiences on average about 83 external requests. Around 90% of the attacks use TCP. The prominent ports are 22 (SSH), 1433/3306 (MSSQL), and 80 (HTTP). We summarize details in Table 2.

4.2.1 Attacks per AS

To explore the topological location of the attacks, we map the source IP addresses of the adversaries to their origin autonomous system (AS) using the common IP to ASN lookup service provided by Team Cymru. We rank each AS separately per network access.

Overall, most of the attacks are initiated from IP prefixes that belong to the same small set of ASes (cf., Figure 2(a)). The top-5 ASes are primarily based in China and Russia and do not cover mobile operators. The distri-

	# Attacked ports per transport protocol				# Attacks per transport protocol			
	UMTS	Darknet	DSL	University	UMTS	Darknet	DSL	University
TCP	111	133	89	252	14,954	55,378	32,781	22,445,580
UDP	76	71	96	22	637	5,583	8,254	480

Table 1: Amount of malicious requests per transport protocol, November 2012

Rank	1	2	3	4	5	6	7	8	9	10
UMTS	22 SSH	1433 MSSQL	3306 MSSQL	5900 VNC	6666	3389 RDP	*1080* *SOCKS*	23 Telnet	*5060* *SIP*	80 HTTP
Darknet	22 SSH	139 NetBIOS	110 POP3	25 SMTP	3306 MSSQL	*91*	5901	5900 VNC	3389 RDP	53 DNS
DSL	*51099*	22 SSH	5900 VNC	110 POP3	25 SMTP	3389 RDP	143 IMAP	6666	1433 MSSQL	23 Telnet
Univ.	*445* *MS AD*	139 NetBIOS	80 HTTP	22 SSH	110 POP3	3389 RDP	5900 VNC	3306 MSSQL	143 IMAP	*5902*

Table 2: Top-10 of the most attacked ports (single events emphasized), November 2012

bution of attacks is enhanced for the university network. The darknet and the DSL home network follow a similar shape, in which the mobile network exhibits a more narrowed distribution. For all network types, it is clearly visible that already a small number of ASes have a significant impact on the attack experiences.

4.2.2 Attackers per AS

In our second statistical analysis, we measure the number of different source IP addresses (i.e., attackers) per AS (cf., Figure 2(b)). Again, we calculate the rank separately for each network access type. This analysis allows us to estimate the amount of different attack sources and to balance the intensity of each attacker. Consequently, the maximal values are three to two orders of magnitude less compared to the number of attacks. Nevertheless, the characteristic shape of the curves in Figure 2(a) still exists.

4.2.3 Comparison with Previous Measurements

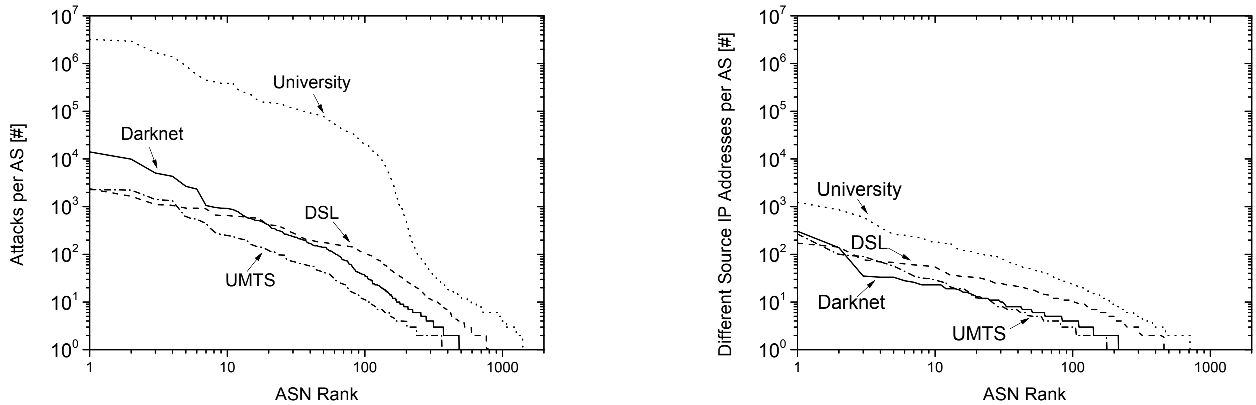
In our previous measurements from January 2012 [4] we found similar results. The most significant difference is the absolute number of attacks on the mobile system and the darknet. In November 2012 the darknet experienced a surprisingly high amount of attacks, indicating that it is more attractive to an attacker compared to the UMTS and home network. This is in general not true as the IP address space of the darknet is officially not related to any external network service. Looking into this in more detail reveals that a small set of nodes connected to the darknet initiating a large portion of requests. This observation is also highlighted by our analysis per attacker.

Similar to this, the UMTS network is not spared by attacks in general. In January 2012, the UTMS nodes suffered on average on the same amount of requests compared to the home network. Interestingly regions and originators of attacks were better pronounced and operate at higher intensity in the beginning of this year. We consider this as an indicator for the liveliness of the mobile regime, which needs further analysis in the future.

5 Conclusion and Outlook

In this paper we presented a mobile honeypot system that allows for a detailed analysis of mobile-specific attacks. A key insight is the abstraction from unnecessary mobility aspects. To study common attacks, the honeypot is neither required to run on a real smartphone, nor on a full-fledged mobile operating system. The mobile honeypot is operated on standard PCs running Linux. This enables the analysis of malicious traffic across different network environments and bears the advantage of simplified long-term maintenance as the same tool basis can be re-used.

We deployed our concept on probes connected to a mobile network, as well as monitoring nodes connected to different types of wired Internet access (i.e., university network, darknet, DSL home network). So far we did not find a relevant ratio of remote attacks that specifically target on the mobile system, neither from non-mobile nor mobile networks. From this perspective we conclude that



(a) Attacks per AS

(b) Attackers per AS

Figure 2: Comparison of requests per autonomous system separately ranked by network access, Nov. 2012

mobile devices are currently more threatened with malicious applications (e.g., trojan horse) compared to external, unsolicited requests via the Internet.

In the future we will still maintain our honeypot setup. We will concentrate on more subtle correlation analysis of how specific groups of attackers behave with the aim to identify individual patterns of mobility related aggressions. We will also analyse attacks per port in more detail, and conduct time series analysis. Due to limited statistics, though, these considerations will require a much longer range of observation. Estimating the error of IP spoofing events on our results is also part of our future work.

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